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PHOTOVOLTAIC CELL OPERATION ON MARS

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ABSTRACT: The Martian surface environment provides peculiar challenges for the operation of solar arrays: low temperature, solar flux with a significant scattered component that varies in intensity and spectrum with the amount of suspended atmospheric dust. and the possiblity of performance loss due to dust deposition on the array surface. This paper presents theoretical analyses of solar cell performance on the surface of Mars and measurements of cells under Mars conditions.
Keywords: Space, Space Cells

1 SOLAR CELLS ON MARS

Operation of solar cells on the Martian surface presents challenges significantly different from those of operating on either the Earth's surface or in orbit. For many proposed Mars probes, the performance of the solar arrays presents the main operational constraint on the allowed latitude of the landing site, on the amount of power available for science operations, and on how long during each day the scientific instruments can operate.

The environmental conditions on the surface of Mars are quite different from the orbital environment in which space solar arrays normally operate [1]. Major differences of the Martian surface from operating conditions of Earth orbit are:

- lower solar intensity due to greater distance of Mars from the sun
- suspended atmospheric dust modifies the solar spectrum and reduces intensity [2-5]
- low operating temperatures
- deposition of dust on the arrays [6]

For Mars surface operation, radiation exposure is not a significant source of degradation.

The redder spectrum of Mars and the low operating temperature tend to favor lower bandgap solar cell technologies. Constraints due to shock and g-loading of the landing are also a factor, as well as flexure of the arrays due to wind. This will favor more robust cell substrate materials. The requirement for small array sizes for roving vehicles, on the other hand, drives the solar cell technology toward high-efficiency solar cell designs, since only a limited amount of array area is available. GaInP/GaAs/Ge triple-junction cells were the technology chosen for the Mars Exploration Rover mission (Figure 1), which landed on Mars in January 2004. (The British Mars lander, Beagle-2, also chose triple-junction cells for the solar arrays, although the mission did not land successfully on Mars).

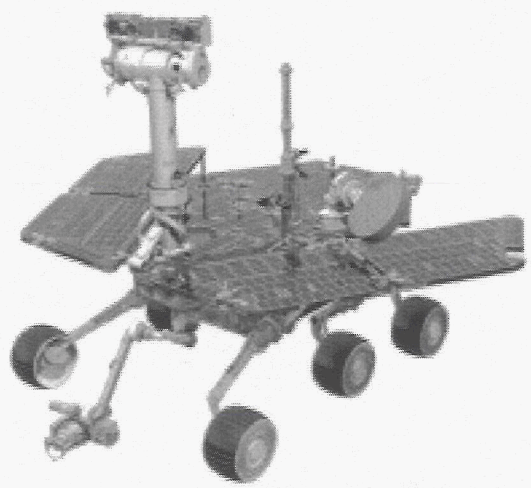

Figure 1: The Mars Exploration Rover (MER) vehicle, with five solar array panels.

2 SOLAR ENERGY

The solar energy on the Martian surface depends on the amount of dust in the atmosphere. Figures 2 and 3 show modeled results of the total solar flux reaching the surface at the MER-1 Gusev Crater landing site for two different dust conditions, a low dust opacity (tau = 0.5) and a high dust opacity (tau = 0.95). The graph shows both the direct and scattered components of the illumination. In the high-dust case, the direct illumination is reduced, while the scattered component is increased. (The actual atmospheric conditions at the landing site showed a

high optical depth, measured at about 0.9, at the landing, and the optical depth decreased during the mission to less than 0.5).

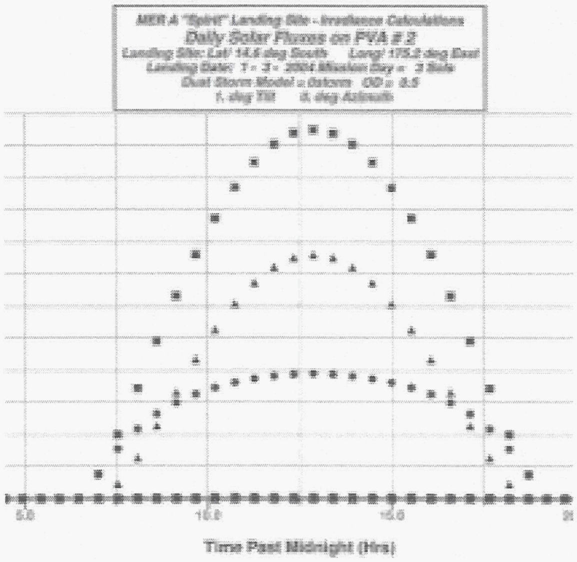

Figure 2: Sunlight on Mars (low dust case, tau = 0.5), showing the direct (circles), scattered (triangles), and total insolation on a horizontal surface during the course of a Martian sol.

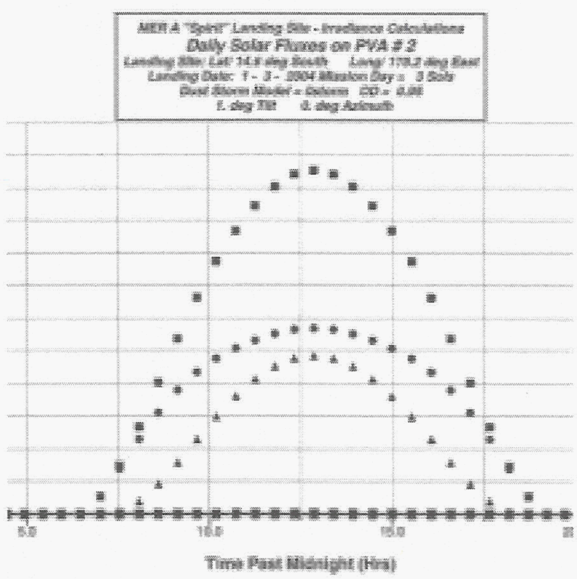

Figure 3: Sunlight on Mars (high dust case, tau = 0.95).

The spectrum is significantly altered by the atmospheric dust. Figure 3 shows an example calculation, for the case of an optical depth tau=1, and zenith angle zero degrees (noon), similar to the conditions at the MER rover sites near the landing day.

In addition, atmospheric dust settles on the solar array [6], both changing the spectrum and also reducing the performance as the mission duration increases

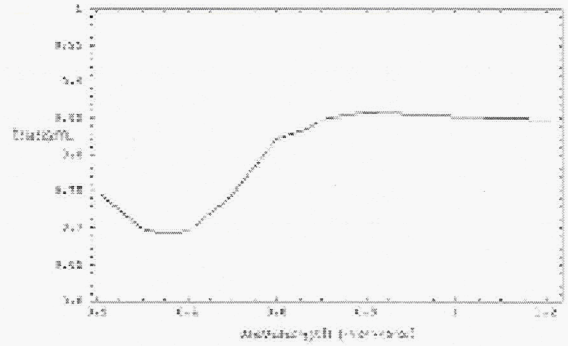

Figure 4: modelled solar spectrum on Mars surface (noon, tau = 1).

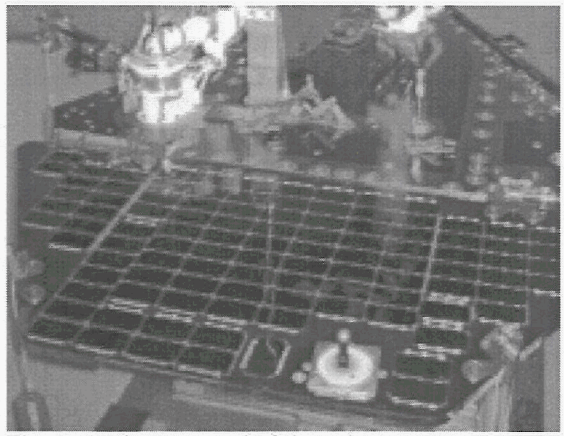

Figure 5: The rear panel of the solar array on the MER rover.

3 OPERATION OF SOLAR CELLS ON MARS

Following the successful use of solar power on the Mars Pathfinder mission, in which both the lander and the rover used GaAs solar cells for primary power, the Mars Exploration Rovers, "Spirit" and "Opportunity," demonstrated the first use of triple-junction GaInP/GaAs/Ge solar cells on the surface of Mars. One of the panels of the array is shown before flight in figure 5.

3.1 Laboratory measurements

The solar cell performance will depend on the spectrum, intensity, and temperature of the arrays. For the triple-junction solar cells used on the MER solar arrays, the short-circuit current is limited by the top sub-cell of the three-cell stack. Figures 6 shows the quantum efficiency of the top GaInP solar cell used in the MER solar arrays, showing that it is primarily responding to the visible and blue spectral range, with a long-wavelength cut-off of about 650 nm (0.65 micrometers).

Figures 7 and 8 show the effect of temperature on the cell performance, showing measurements made at both 1 AU (Earth distance) and Mars intensity under simulated AM0 solar spectrum,

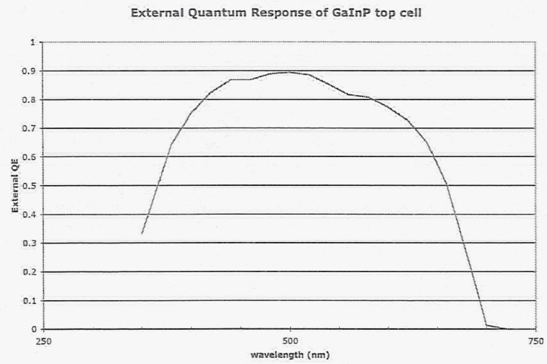

Figure 6: Measured external quantum efficiency of the top sub-cell of the MER rover solar array.

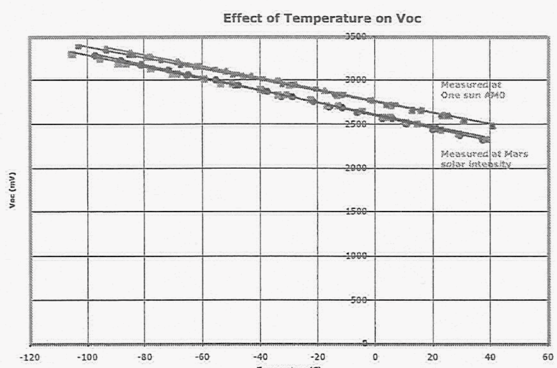

Figure 7: Effect of temperature on cell open circuit voltage at AM0 Earth solar intensity (top curves) and Mars solar intensity (bottom).

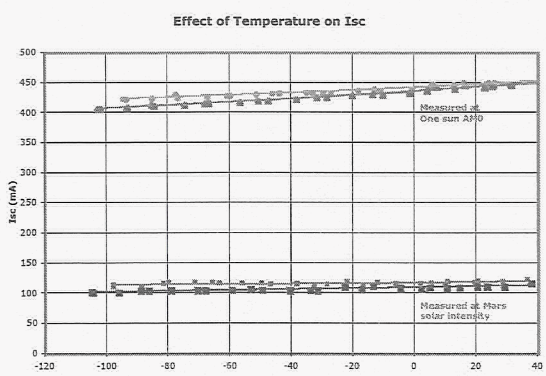

Figure 8: Effect of temperature on cell short-circuit current at AM0 Earth solar intensity (top) and Mars solar intensity (bottom).

3.2 Operation on Mars

As of 135 sols after the landing of Spirit on the surface of Mars, the solar arrays of both rovers are continuing to perform well on the surface of Mars. Figure 9 shows the right wing of the solar array, as viewed by the pancam on the surface of Mars. Figure 10 shows the operational result for the first full day on Mars, showing excellent performance of the triple junction cells under Mars conditions.

Dust deposition on the solar arrays is being measured, but is not currently a limiting factor on the array performance.

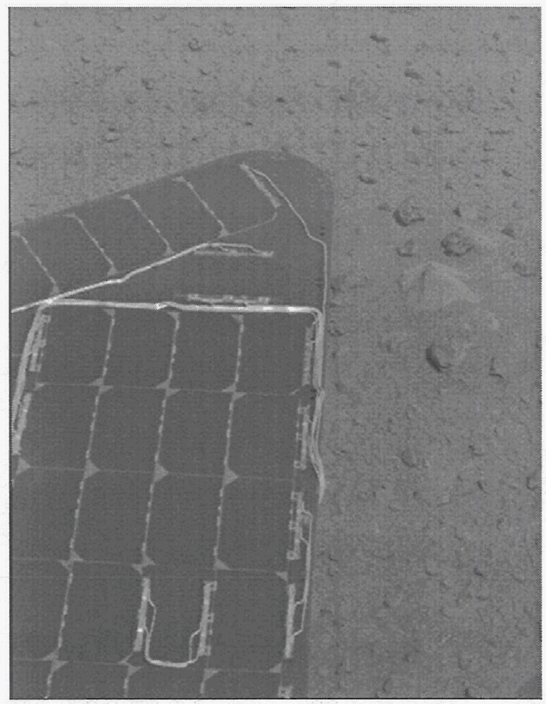

Figure 9: MER Solar array on Mars

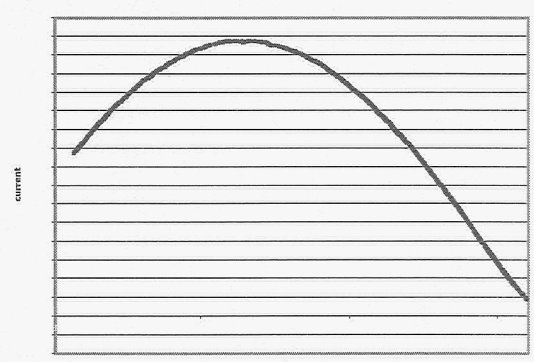

Figure 10: Short circuit current during the first day on Mars

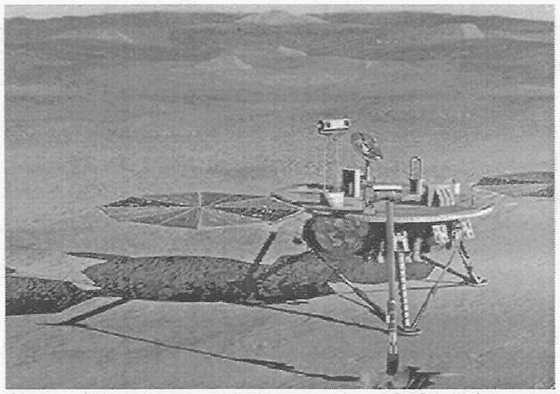

Figure 11: Future missions: The 2007 "Phoenix" mission to the Martian polar regions will use a n advanced flexible solar array.

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